NITRIDE BASED SEMICONDUCTOR
PHOTO-LUMINESCENT DEVICE

5

BACKGROUND OF THE INVENTION

. The present invention relates to a nitride based semiconductor

10 device, and more particularly to a nitride based semiconductor photo-luminescent device.

A nitride based semiconductor is an extremely important material for a blue-color laser diode. In Jpn. J. Appl. Phys. Vol. 36 (1997), pp. L1568-1571, Nakamura et al. reported that a continuous photo-

15 luminescence life-time over 10,000 hours at 2 mW output at room temperature was confirmed. FIG. 1 is a fragmentary cross sectional elevation view illustrative of a first conventional nitride based semiconductor laser diode. In order to increase the life-time of the laser diode, it is essential to reduce the dislocation density of the active layer.

20 The first conventional nitride based semiconductor laser diode has the following structure. A stripe-shaped silicon dioxide mask 103 having window regions is selectively formed over a gallium nitride layer 102 over a top surface of a sapphire substrate 101, so that a gallium nitride layer is grown over the stripe-shaped silicon dioxide mask 103 and over the

gallium nitride layer 102, wherein the gallium nitride layer has low dislocation density regions 104 which are positioned over the stripe-shaped silicon dioxide mask 103. A p-electrode 105 is positioned over the low dislocation density region 104.

5   A gallium nitride layer 102 is grown on the sapphire substrate 101 by a metal organic chemical vapor deposition method. The sapphire substrate 101 has a high surface dislocation density. The gallium nitride layer 102 has a high dislocation density. A stripe-shaped silicon dioxide mask 103 having window regions is formed over the gallium nitride layer

10   102 in a [1,-1,0,0]-direction. A gallium nitride layer 106 is grown by a metal organic chemical vapor deposition method using the stripe-shaped silicon dioxide mask 103 with the window regions. The gallium nitride layer 106 has a high dislocation density region 116 and a low dislocation density region 104. The high dislocation density region 116 is formed on

15   the gallium nitride layer 102 having a high dislocation density. The high dislocation density region 116 is grown in a vertical direction from gallium nitride layer 102 having a high dislocation density shown by the window regions of the stripe-shaped silicon dioxide mask 103, for which reason the dislocation is propagated from the gallium nitride layer 102 to the high

20   dislocation density region 116, whereby the high dislocation density region 116 has a high dislocation density. The low dislocation density region 104 is formed over the stripe-shaped silicon dioxide mask 103. The low dislocation density region 104 is grown by the epitaxial lateral overgrowth from the window regions of the stripe-shaped silicon dioxide mask 103.

Page 2

The stripe-shaped silicon dioxide mask 103 cuts the further propagation of the dislocation from the sapphire substrate 101. The low dislocation density region 104 has a low dislocation density. At the center of the low dislocation density region 104, epitaxial lateral overgrowths of gallium

5   nitride in various lateral directions from the window regions of the stripe-shaped silicon dioxide mask 103 come together, whereby new dislocations are formed, for which reason the center region of the low dislocation density region 104 has a high dislocation density. As a result, an Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100 is

10   completed which has the high dislocation density region 116 and the low dislocation density region 104.

An Si-doped n-type $In_{0.1}Ga_{0.9}N$ layer 107 is formed over the Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100. An n-type cladding layer 108 is formed over the Si-doped n-type $In_{0.1}Ga_{0.9}N$

15   layer 107, wherein the n-type cladding layer 108 comprises 120 periods of alternating laminations of an Si-doped n-type GaN layer having a thickness of 2.5 nanometers and an undoped $Al_{0.14}Ga_{0.86}N$ layer having a thickness of 2.5 nanometers. An Si-doped n-type GaN optical confinement layer 109 having a thickness of 0.1 micrometers is formed over the n-type cladding

20   layer 108. A multiple quantum well active layer 210 is formed over the Si-doped n-type GaN optical confinement layer 109, wherein the multiple quantum well active layer 210 comprises alternating laminations of Si-doped n-type $In_{0.15}Ga_{0.85}N$ quantum well layer having a thickness of 3.5 nanometers and an Si-doped n-type $In_{0.02}Ga_{0.98}N$ potential barrier layer

having a thickness of 10.5 nanometers. An Mg-doped p-type $Al_{0.2}Ga_{0.8}N$ cap layer 111 having a thickness of 20 nanometers is formed over the multiple quantum well active layer 210. An Mg-doped p-type GaN optical confinement layer 112 having a thickness of 0.1 micrometer is formed over the Mg-doped p-type $Al_{0.2}Ga_{0.8}N$ cap layer 111. A p-type cladding layer 113 is formed over the Mg-doped p-type GaN optical confinement layer 112, wherein the p-type cladding layer 113 comprises 120 periods of alternating laminations of an Mg-doped p-type GaN layer having a thickness of 2.5 nanometers and an undoped $Al_{0.14}Ga_{0.86}N$ layer having a thickness of 2.5 nanometers. An Mg-doped p-type GaN contact layer 114 having a thickness of 0.05 micrometers is formed over the p-type cladding layer 113. The lamination structure over the Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100 is selectively removed by a dry etching process to form a ridge structure over a predetermined region of the top surface of the Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100, wherein the ridge structure comprises laminations of the Si-doped n-type $In_{0.1}Ga_{0.9}N$ layer 107, the n-type cladding layer 108, the Si-doped n-type GaN optical confinement layer 109, the multiple quantum well active layer 210, the Mg-doped p-type $Al_{0.2}Ga_{0.8}N$ cap layer 111, the Mg-doped p-type GaN optical confinement layer 112, the p-type cladding layer 113 and the Mg-doped p-type GaN contact layer 114. The Mg-doped p-type GaN contact layer 114 is positioned over the low dislocation density region 104 for current injection into the low dislocation density region 104. A p-electrode 105 is formed on

Page 4

the Mg-doped p-type GaN contact layer 114, wherein the p-electrode 105 comprises an Ni layer and an Au layer. An n-electrode 115 is also selectively formed over the top surface of the Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100, wherein the n-electrode

5   115 comprises an Ni layer and an Au layer. The n-electrode 115 is also positioned over the low dislocation density region 104 for current injection into the low dislocation density region 104.

The gallium nitride substrate formed in the above conventional method is so called to as "epitaxial lateral overgrowth gallium nitride

10   substrate". The sapphire substrate 101 has a high surface dislocation density. The gallium nitride layer 102 grown over the sapphire substrate 101 also has a high dislocation density. The gallium nitride layer 106 has a high dislocation density region 116 positioned over the window regions of the stripe-shaped silicon dioxide mask 103 and a low dislocation density

15   region 104 positioned over the stripe-shaped silicon dioxide mask 103. The high dislocation density region 116 of the gallium nitride layer 106 was grown over the gallium nitride layer 102 having the high dislocation density, for which reason the high dislocation density region 116 of the gallium nitride layer 106 also has a high dislocation density. The stripe-

20   shaped silicon dioxide mask 103 is made of silicon dioxide free of dislocation, for which reason the low dislocation density region 104 grown over the stripe-shaped silicon dioxide mask 103 has a low dislocation density. The high dislocation density region 116 has a high dislocation density of 1×10^{12} m^{-2}. The stripe-shaped silicon dioxide mask 103 cuts

Page 5

the propagation of the dislocation from the sapphire substrate 101. The low dislocation density region 104 has a low dislocation density of 1×10^{11} m^{-2}. The low dislocation density region 104 is formed by the epitaxial lateral overgrowth of gallium nitride from the window regions of the stripe-shaped

5   silicon dioxide mask 103. At the center of the low dislocation density region 104, epitaxial lateral overgrowths of gallium nitride in various lateral directions from the window regions of the stripe-shaped silicon dioxide mask 103 come together, whereby new dislocations are formed, for which reason the center region of the low dislocation density region 104

10   has a high dislocation density. In FIG. 1, the high dislocation density region is represented by dot marks. The p-electrode 105 is formed over the low dislocation density region 104 except for its center region, so that a current is injected from the p-electrode 105 into the low dislocation density region of the active layer. If the current is injected into the high dislocation density

15   region, then the deterioration in performance of the device is likely to appear. However, if the current is injected into the low dislocation density region, then the deterioration in performance of the device is unlikely to appear, resulting in a long life-time of the device.

A second conventional method of forming a low dislocation

20   density region was reported by Nakamura et al. in Applied Physics vol. 68-7, pp. 793-796. A GaN layer is formed on a sapphire substrate. The GaN layer is selectively removed by a dry etching process to form stripe-shaped GaN layers. Further, a GaN layer is formed over the stripe-shaped GaN layers and over the sapphire substrate. The GaN layer is epitaxially grown

in vertical direction from the top surfaces of the stripe-shaped GaN layers and also epitaxially grown by an epitaxial lateral overgrowth in lateral direction from the top surfaces of the stripe-shaped GaN layers toward the top surface of the sapphire substrate. This growth will hereinafter referred

5   to as a "mask-less epitaxial lateral overgrowth". The GaN layer has a high dislocation density region over the stripe-shaped GaN layer and a low dislocation density region over the sapphire substrate. Namely, the low dislocation density region is grown by the epitaxial lateral overgrowth from the stripe-shaped GaN layers to the region over the uncovered top surface

10   of the sapphire substrate. The stripe-shaped GaN layer has a high dislocation density. The dislocation of the stripe-shaped GaN layer is propagated to the high dislocation density region grown in the vertical direction over the stripe-shaped GaN layers. The dislocation of the stripe-shaped GaN layer is propagated to the low dislocation density region

15   grown by the epitaxial lateral overgrowth from the stripe-shaped GaN layers to the region over the uncovered top surface of the sapphire substrate. A current is injected into the low dislocation density region to obtain a long life-time.

The present inventors reported in Jpn. J. Appl. Phys. Vol. 36

20   (1997), pp. L899-902 and in NEC Research and Development vol. 41 (2000) No. 1 pp. 74-85 that a low dislocation density region is formed in an entire region of the active layer or an entire region of the substrate by a facet-initiated epitaxial lateral overgrowth method using the stripe-shaped silicon dioxide masks. In accordance with the facet-initiated epitaxial

lateral overgrowth, the stripe-shaped silicon dioxide masks are formed over the gallium nitride layer over the sapphire substrate to carry out a hydride vapor phase epitaxial growth, wherein the through dislocations are curved, whereby the high dislocation density region as the epitaxial lateral overgrowth is not formed. Thus, the dislocation density is suppressed low over the entire of the substrate.

As the technique for forming the low dislocation density GaN region has been progressed, then the life-time of the blue color nitride based semiconductor laser diode, which emits a laser beam of a wavelength in the range of about 400-500 nanometers, has been greatly improved.

The technique for doping silicon into the active layer has been used for improving the laser device performances such as the threshold current density. In Japanese laid-open patent publication No. 10-12969, it is disclosed that silicon impurity is doped into the active layer at an impurity concentration n the range of 1×10^{19} m^{-3} to 1×10^{21} m^{-3} for improvement in the laser threshold value.

In Applied Physics Letter 73 (1998), pp. 496-498 and Proc. of the 2nd Int. Sym. on Blue Laser and Light Emitting Diodes (1998), p. 381, it is disclosed that the active layer is doped with silicon to reduce the threshold value. The mechanism of the threshold value reduction due to the silicon doping process to the active layer might be associated with a piezo electric field shielding effect due to the impurity doping and the improvement in the planarity of the quantum well structure. It has been known that the improvement of the laser device performance is obtainable

by the silicon doping. It is the common technical sense that the advanced nitride based semiconductor laser diode has the active layer which is doped with silicon in the above technical viewpoint.

5   In view of the actual practical use of the laser diode, the reliability of the conventional nitride based semiconductor laser diode is still insufficient. If the nitride based semiconductor laser diode having a wavelength band of about 400-500 nanometers is used for emitting a laser beam for an optical disk such as a digital video disk, a long life-time of not less than 5000 hours at 30 mW and at 70°C is necessary in consideration of

10   the wiring operation. As reported by Nakamura et al. in JSAP International No. 1, pp. 5-17 (2000), the life-time of the conventional nitride based semiconductor laser diodes is only 500 hours at 30 mW and at 60°C.

In the above circumstances, it had been required to develop a novel nitride based semiconductor photo-luminescent device free from the

15   above problem.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a

20   novel nitride based semiconductor photo-luminescent device free from the above problems.

It is a further object of the present invention to provide a novel nitride based semiconductor photo-luminescent device having a long life-time under high temperature and high output conditions.

Page 9

The present invention provides a nitride based semiconductor photo-luminescent device having an active layer having a quantum well structure, the active layer having both at least a high dislocation density region and at least a low dislocation density region lower in dislocation

5   density than the high dislocation density region, wherein the low dislocation density region includes a current injection region into which a current is injected, and the active layer is less than 1×10^{18} m^{-3} in impurity concentration.

    The above and other objects, features and advantages of the

10   present invention will be apparent from the following descriptions.

BRIEF DESCRIPTION OF THE DRAWINGS

    Preferred embodiments according to the present invention will be

15   described in detail with reference to the accompanying drawings.

    FIG. 1 is a fragmentary cross sectional elevation view illustrative of a first conventional nitride based semiconductor laser diode.

    FIG. 2 is a fragmentary cross sectional elevation view illustrative of a first novel nitride based semiconductor laser diode in a first

20   embodiment according to the present invention.

    FIG. 3 is a fragmentary cross sectional elevation view illustrative of a second novel nitride based semiconductor laser diode in a second embodiment according to the present invention.

    FIG. 4 is a fragmentary cross sectional elevation view illustrative

Page 10

of a third novel nitride based semiconductor laser diode in a third embodiment according to the present invention.

DISCLOSURE OF THE INVENTION

5

The present inventors found out the extremely important and unexpectable facts that if the active layer is undoped of the nitride based semiconductor laser device formed over the facet-initiated epitaxial lateral overgrowth gallium nitride substrate, then a low threshold value is obtained

10 and a longer life-time is also obtained.

The present inventors investigated inter-relationships of the dislocation density distribution, the impurity concentration profile of the active layer, the threshold value of the laser device and the device life-time, wherein the laser diodes are concurrently formed over both different type

15 substrates, for example, the facet-initiated epitaxial lateral overgrowth substrate and the epitaxial lateral overgrowth substrate to prepare the first type semiconductor photo-luminescent devices over the facet-initiated epitaxial lateral overgrowth substrates and also prepare the second type semiconductor photo-luminescent devices over the epitaxial lateral

20 overgrowth substrate. Furthermore, the first type semiconductor photo-luminescent devices over the facet-initiated epitaxial lateral overgrowth substrates may be classified into three different types in Si-impurity concentration in the quantum well active layer.

The first semiconductor photo-luminescent device is formed over

the facet-initiated epitaxial lateral overgrowth substrate and has the Si-undoped quantum well active layer. The second semiconductor photo-luminescent device is formed over the facet-initiated epitaxial lateral overgrowth substrate and has the Si-doped quantum well active layer

5   having a low Si-impurity concentration of 1×10^{18} m^{-3}. The third semiconductor photo-luminescent device is formed over the facet-initiated epitaxial lateral overgrowth substrate and has the Si-doped quantum well active layer having a high Si-impurity concentration of 5×10^{18} m^{-3}. The fourth semiconductor photo-luminescent device is formed over the

10   epitaxial lateral overgrowth substrate and has the Si-undoped quantum well active layer. The fifth semiconductor photo-luminescent device is formed over the epitaxial lateral overgrowth substrate and has the Si-doped quantum well active layer having a low Si-impurity concentration of 1×10^{18} m^{-3}. The sixth semiconductor photo-luminescent device is formed

15   over the epitaxial lateral overgrowth substrate and has the Si-doped quantum well active layer having a high Si-impurity concentration of 5×10^{18} m^{-3}.

The above first to sixth semiconductor photo-luminescent devices have the same structure as what will be described below in the first

20   embodiment. For the epitaxial lateral overgrowth substrate, a silicon diode mask pattern is used which has a mask width of 20 micrometers and a window of 5 micrometers. This silicon dioxide mask pattern is much wider than the usual silicon dioxide mask pattern having a mask width of not more than about 10 micrometers for the epitaxial lateral overgrowth

substrate. If the mask width is wide, then the wide silicon dioxide mask is buried with the gallium nitride layer by the lateral growth. This makes it difficult to obtain a highly plane layer over the wide silicon dioxide mask. This allows formation of a large low dislocation density region. In accordance with the present invention, a growth condition, for example, a flow rate ratio of Group III element source material and Group V element source material is optimized for forming a planer burying gallium nitride layer grown by the lateral growth over the wide silicon dioxide mask.

Table 1 shows averaged values of individual initial threshold current densities of the above first to sixth nitride based semiconductor laser emitting devices and the degrees of individual deteriorations of the above first to sixth nitride based semiconductor laser emitting devices after APC examination for 100 hours under high temperature and high output conditions of 70°C and 30 mW.

Table 1

	Threshold current density	deterioration
First device	20 (mA/m^2)	no deterioration
Second device	22 (mA/m^2)	no deterioration
Third device	24 (mA/m^2)	no deterioration
Fourth device	23 (mA/m^2)	no deterioration
Fifth device	24 (mA/m^2)	no deterioration
Sixth device	23 (mA/m^2)	slight voltage rise

Threshold current density : initial threshold current density.

Page 13

The first device :   facet-initiated epitaxial lateral overgrowth ; and

Si-undoped quantum well active layer.

The second device : facet-initiated epitaxial lateral overgrowth ; and

Si-doped quantum well active layer of 1×10^{18} m^{-3}.

5   The third device :   facet-initiated epitaxial lateral overgrowth ; and

Si-doped quantum well active layer of 5×10^{18} m^{-3}.

The fourth device : epitaxial lateral overgrowth ; and

Si-undoped quantum well active layer.

The fifth device :   epitaxial lateral overgrowth ; and

10   Si-doped quantum well active layer of 1×10^{18} m^{-3}.

The sixth device :   epitaxial lateral overgrowth ; and

Si-doped quantum well active layer of 5×10^{18} m^{-3}.

There is no large difference in the initial threshold current density

15   in the first to sixth nitride-based semiconductor laser emitting devices. In

the first and second nitride-based semiconductor laser emitting devices

grown over the facet-initiated epitaxial lateral overgrowth substrates and

having the Si-undoped active layer and the Si-doped active layer of $1 \times$

10^{18} m^{-3}, the initial threshold current densities are slightly lower than the

20   remaining initial threshold current densities of the third to sixth nitride-

based semiconductor laser emitting devices, even the Si-impurity

concentrations are lower than 1×10^{19} m^{-3}. This means that the initial

threshold current density has no large dependency upon the Si-impurity

concentration. In the first to third nitride-based semiconductor laser

Page 14

emitting devices grown over the facet-initiated epitaxial lateral overgrowth substrates, the first nitride-based semiconductor laser emitting device has the lowest initial threshold current density, and the second nitride-based semiconductor laser emitting device has the second lowest initial threshold current density. If the nitride-based semiconductor laser emitting devices are grown over the facet-initiated epitaxial lateral overgrowth substrates, then the Si-undoped active layer obtains the lowest initial threshold current density. Further, the first to third nitride-based semiconductor laser emitting devices grown over the facet-initiated epitaxial lateral overgrowth substrates are free from any deterioration in performance. The fourth and fifth nitride-based semiconductor laser emitting devices grown over the epitaxial lateral overgrowth substrates and having the Si-undoped active layer and the Si-doped active layer of 1×10^{18} m^{-3} are also free from any deterioration in performance. Only the sixth nitride-based semiconductor laser emitting device grown over the epitaxial lateral overgrowth substrate and having the Si-doped active layer of 5×10^{18} m^{-3} shows a slight deterioration, for example, a slight voltage raise.

The above experimental results show that the deterioration of the device in the high temperature and high output operation relates to both the presence of the high dislocation density region and the Si-impurity concentration. If the low dislocation density region is entirely grown over the substrate by the facet-initiated epitaxial lateral overgrowth, then the deterioration is unlikely to appear. If not only the low dislocation density region but also the high dislocation density region are grown over the

substrate by the epitaxial lateral overgrowth and if the current is injected into the low dislocation density region, then the deterioration is likely to appear. If not only the low dislocation density region but also the high dislocation density region are grown over the substrate by the epitaxial

5   lateral overgrowth and if the impurity concentration of the active layer is small, then the deterioration is unlikely to appear.

Those mechanisms might be considered as follows. Under the high temperature and high output conditions, a large current flows through the device and a large heat generation is also caused, and further an

10   intensity of the photo-luminescence is high. The heat energy and the energy of photons causes that the dislocations in non-current region outside the active layer extend to the active region, through which a current flows. Once the high discoloration density region reaches the active region, then the deterioration is likely to appear. Doping impurity into the active layer

15   provides an influence to the extension of the dislocations. The impurity introduction causes the local strain in the crystal, thereby making the dislocation further extend and move, and further thereby causes that the photon is absorbed into the impurity level to generate a heat which promotes the extension and motion of the dislocation.

20   In order to prevent the deteriorations of the device, it is preferable that the entire region of the device is reduced in dislocation density. If the facet-initiated epitaxial lateral overgrowth substrate is used, the low dislocation density region extends entirely over the substrate. It is necessary for forming the facet-initiated epitaxial lateral overgrowth

substrate to prepare not only the metal organic vapor phase epitaxy growth system but also a hydride vapor phase epitaxy growth system. This results in the high manufacturing cost. At the present, the epitaxial lateral overgrowth method and the mask-less epitaxial lateral overgrowth method

5   are advantageous in cost reduction.

If the gallium nitride substrate is prepared by the epitaxial lateral overgrowth method or the mask-less epitaxial lateral overgrowth method, then the following two methods are effective to improve the device life-time under the high temperature and high output conditions. The first

10   method is that the width of the silicon dioxide mask in the epitaxial lateral overgrowth method or the width of the sapphire-exposed region in the mask-less epitaxial lateral overgrowth method is wide to reduce the influence by the high dislocation density region. The second method is that the impurity concentration of the active layer is reduced to suppress the

15   further extension or move of the high dislocation density region to the low dislocation density region.

The above first method needs the large area to be buried by the lateral overgrowth. This means that the growth time necessary for burying the large area by the lateral overgrowth is long, and further makes it

20   difficult to form a plane or flat layer. Notwithstanding, it is possible to bury the flat layer over the large area, for example, the mask width of about 30 micrometers or the sapphire-exposed area of about 30 micrometers under the selected conditions for the lateral overgrowth, for example, the TMG flow rate is not more than 1 micro-mol per 1 minute.

Page 17

The above second method is opposite to the conventional common sense that doping the silicon impurity reduces the threshold current density. As described above, the present inventors confirmed the fact that the large variation of the threshold current density is independent

5   from the silicon impurity concentration. The experimental results using the facet-initiated epitaxial lateral overgrowth show it is important that the current injection region of the active layer has a low dislocation density and has a reduced number of defects.

The dislocation core causes the non-photo-luminescent re-

10   combination of carriers. In order to suppress the non-photo-luminescent re-combination of carriers, it is effective to increase the impurity concentration of the active layer to shorten the carrier diffusion length thereby suppressing carriers from flowing into the dislocation cores. It has been known that if the impurity concentration is not less than 1×10^{19} m^{-3},

15   then Auger re-combination as the non-photo-luminescent re-combination of carriers frequently appears.

In accordance with the conventional common sense, if the dislocation density of the active layer is high, and the impurity concentration is increased to prevent the non-photo-luminescent re-

20   combination at the dislocation cores. The above experimental results show that if the current is injected into the largely reduced dislocation density region, it is more important to reduce the Auger re-combination rather reduce the non-photo-luminescent re-combination at the dislocation cores.

If the active layer comprises a single layered structure of a

thickness of not less than 10 nanometers in place of the quantum well structure, the reduction of the Si-impurity concentration into less than 1×10^{18} m^{-3} provides a smaller effect for improving the life-time than when the active layer comprises the quantum well structure. If the single layered

5 structure of the active layer has a thickness of less than 10 nanometers, then the quantum effect possessed by the quantum well structure appears, wherein the state density has an abrupt rising edge which increases an optical gain and decreases the threshold current density value, whereby the temperature-dependent characteristics are improved. In this case, the

10 reduction of the Si-impurity concentration into less than 1×10^{18} m^{-3} provides a remarkable effect of improving the life-time as in case of the quantum well active layer.

The following is one of the reasons why the effect of improving the life-time is less remarkable if the active layer comprises a thick single

15 layered structure of the thickness of more than 10 nanometers in place of the quantum well structure and if the Si-impurity concentration is less than 1×10^{18} m^{-3}. The reduction in the Si-impurity concentration of the thick single layered active layer increases the series resistance, whereby the heat generation is increased. The increase in the heat generation causes that

20 even if the Si-impurity concentration is low, then the dislocations are likely to extend and move.

If the active layer comprises the quantum well structure, then the increase in the Si-impurity concentration shortens the life-time. As compared to the single layered active layer, a ratio in area of the interface

Page 19

to the volume of the active layer is remarkably increased. A segregation of the Si-impurity appears on the interface. Not only the interface recombination speed is increased, but also the extension and move of the dislocations are enhanced.

5   In accordance with the present invention, the following structures are provided for solving the above issues based on the above technical viewpoint.

The first present invention provides a nitride based semiconductor photo-luminescent device having an active layer having a

10   quantum well structure, the active layer having both at least a high dislocation density region and at least a low dislocation density region lower in dislocation density than the high dislocation density region, wherein the low dislocation density region includes a current injection region into which a current is injected, and the active layer is less than $1 \times$

15   10^{18} m^{-3} in impurity concentration.

Since the low dislocation density region includes a current injection region into which a current is injected, and the active layer is less than 1×10^{18} m^{-3} in impurity concentration, then the Auger recombination is suppressed and also the extension and move of the high dislocation

20   density region into the current injection region in the low dislocation density region are suppressed, whereby the device life-time under the high temperature and high output conditions is remarkably and greatly improved.

It is preferable that the nitride based semiconductor photo-

luminescent device as claimed in claim 1, wherein a dislocation density of the low dislocation density region is not more than one tenth of a dislocation density of the high dislocation density region.

It is also preferable that a dislocation density of the current injection region is not more than one tenth of an averaged dislocation density of the active layer.

It is also preferable that a dislocation density of at least a part of the high dislocation density region is not less than 1×10^{12} m^{-2}, and an average dislocation density of the current injection region in the low dislocation density region is less than 1×10^{11} m^{-2}.

It is also preferable that an average dislocation density of the active layer is not less than 1×10^{12} m^{-2}, and an average dislocation density of the current injection region in the low dislocation density region is less than 1×10^{11} m^{-2}.

Since the dislocation density of the current injection region is not more than one tenth of the dislocation density of the high dislocation density region, and further the active layer is less than 1×10^{18} m^{-3} in impurity concentration, then the effect is obtained for suppressing the dislocations from the extension and move from the high density dislocation region to the low dislocation density region, particularly into the current injection region.

It is also preferable that an average dislocation density of the current injection region is less than 1×10^{11} m^{-2}, and an average dislocation density of a peripheral region within a distance of 5

micrometers from the current injection region in the low dislocation density region is not less than 1×10^{12} m^{-2}.

It is also preferable that a current injection electrode is provided over an upper semiconductor layer overlying the active layer, and the active layer has an under-positioned region which is positioned under the current injection electrode, and an average dislocation density of the under-positioned region of the active layer is less than 1×10^{11} m^{-2}, and an average dislocation density of a peripheral region within a distance of 5 micrometers from the under-positioned region is not less than 1×10^{12} m^{-2}.

It is also preferable that an average dislocation density of a peripheral region within a distance of 5 micrometers from the current injection region in the low dislocation density region is not more than one tenth of an average dislocation density of the current injection region.

It is also preferable that a current injection electrode is provided over an upper semiconductor layer overlying the active layer, and the active layer has an under-positioned region which is positioned under the current injection electrode, and an average dislocation density of the under-positioned region of the active layer is not more than one tenth of an average dislocation density of an average dislocation density of a peripheral region within a distance of 5 micrometers from the under-positioned region.

Since a higher dislocation density region having a dislocation density of not less than ten times of a dislocation density of the current injection region is present in a peripheral region within a distance of 5

Page 22

micrometers from the current injection region, and the active layer is less than 1×10^{18} m^{-3} in impurity concentration, then the effect is obtained for suppressing the dislocations from the extension and move from the high density dislocation region to the low dislocation density region, particularly

5   into the current injection region.

It is also preferable that the nitride based semiconductor photoluminescent device is provided over mask patterns provided on a gallium nitride top surface of an epitaxial lateral overgrowth substrate. This structure is advantageous in cost reduction as compared to the facet

10   initiated epitaxial lateral overgrowth substrate.

It is also preferable that the mask patterns have a mask width of not less than 25 micrometers to increase the width of the low dislocation density region for suppressing the influence by the high dislocation density region and for obtaining the high reliability under the high temperature and

15   high output conditions.

It is also preferable that the nitride based semiconductor photoluminescent device is provided over selectively provided gallium nitride layers over a semi-insulating substrate of a mask-less epitaxial lateral overgrowth substrate. This structure is advantageous in cost reduction as

20   compared to the facet-initiated epitaxial lateral overgrowth substrate.

It is also preferable that the selectively provided gallium nitride layers have at least a window region having a window width of not less than 25 micrometers to increase the width of the low dislocation density region for suppressing the influence by the high dislocation density region

and for obtaining the high reliability under the high temperature and high output conditions.

It is also preferable that the active layer is undoped.

It is also preferable that the active layer comprises a multiple quantum well structure comprising alternating laminations of undoped quantum well layers and undoped potential barrier layers.

It is also preferable that the active layer comprises a multiple quantum well structure comprising alternating laminations of undoped quantum well layers and Si-doped potential barrier layers having an impurity concentration of less than 1×10^{18} m^{-3}.

It is also preferable that the active layer comprises a multiple quantum well structure comprising alternating laminations of Si-doped quantum well layers having an impurity concentration of less than 1×10^{18} m^{-3} and undoped potential barrier layers.

It is also preferable that the active layer comprises a multiple quantum well structure comprising alternating laminations of Si-doped quantum well layers having an impurity concentration of less than 1×10^{18} m^{-3} and Si-doped potential barrier layers having an impurity concentration of less than 1×10^{18} m^{-3}.

The second present invention provides a nitride based semiconductor photo-luminescent device having an active layer over an epitaxial lateral overgrowth substrate having a dielectric mask pattern with a window region, the active layer having both at least a high dislocation density region positioned over the window region and at least a low

dislocation density region positioned over the dielectric mask pattern, and the low dislocation density region being lower in dislocation density than the high dislocation density region, wherein the low dislocation density region includes a current injection region into which a current is injected,

5   and the active layer is less than 1×10^{18} m^{-3} in impurity concentration.

It is preferable that a dislocation density of the low dislocation density region is not more than one tenth of a dislocation density of the high dislocation density region.

It is also preferable that a dislocation density of the current

10   injection region is not more than one tenth of an averaged dislocation density of the active layer.

It is also preferable that a dislocation density of at least a part of the high dislocation density region is not less than 1×10^{12} m^{-2}, and an average dislocation density of the current injection region in the low

15   dislocation density region is less than 1×10^{11} m^{-2}.

It is also preferable that an average dislocation density of the active layer is not less than 1×10^{12} m^{-2}, and an average dislocation density of the current injection region in the low dislocation density region is less than 1×10^{11} m^{-2}.

20   It is also preferable that an average dislocation density of the current injection region is less than 1×10^{11} m^{-2}, and an average dislocation density of a peripheral region within a distance of 5 micrometers from the current injection region in the low dislocation density region is not less than 1×10^{12} m^{-2}.

Page 25

It is also preferable that a current injection electrode is provided over an upper semiconductor layer overlying the active layer, and the active layer has an under-positioned region which is positioned under the current injection electrode, and an average dislocation density of the under-

5 positioned region of the active layer is less than 1×10^{11} m^{-2}, and an average dislocation density of a peripheral region within a distance of 5 micrometers from the under-positioned region is not less than 1×10^{12} m^{-2}.

It is also preferable that an average dislocation density of a peripheral region within a distance of 5 micrometers from the current

10 injection region in the low dislocation density region is not more than one tenth of an average dislocation density of the current injection region.

It is also preferable that a current injection electrode is provided over an upper semiconductor layer overlying the active layer, and the active layer has an under-positioned region which is positioned under the current

15 injection electrode, and an average dislocation density of the under-positioned region of the active layer is not more than one tenth of an average dislocation density of an average dislocation density of a peripheral region within a distance of 5 micrometers from the under-positioned region.

20 It is also preferable that a higher dislocation density region having a dislocation density of not less than ten times of a dislocation density of the current injection region is present in a peripheral region within a distance of 5 micrometers from the current injection region.

It is also preferable that the dielectric mask patterns have a mask

Page 26

width of not less than 25 micrometers.

It is also preferable that the dielectric mask patterns comprise single-layered dielectric mask patterns.

It is also preferable that the dielectric mask patterns comprise

5 dielectric multilayer reflective mirrors.

It is also preferable that the active layer is undoped.

It is also preferable that the active layer comprises a multiple quantum well structure comprising alternating laminations of undoped quantum well layers and undoped potential barrier layers.

10 It is also preferable that the active layer comprises a multiple quantum well structure comprising alternating laminations of undoped quantum well layers and Si-doped potential barrier layers having an impurity concentration of less than 1×10^{18} m^{-3}.

It is also preferable that the active layer comprises a multiple

15 quantum well structure comprising alternating laminations of Si-doped quantum well layers having an impurity concentration of less than 1×10^{18} m^{-3} and undoped potential barrier layers.

It is also preferable that the active layer comprises a multiple quantum well structure comprising alternating laminations of Si-doped

20 quantum well layers having an impurity concentration of less than 1×10^{18} m^{-3} and Si-doped potential barrier layers having an impurity concentration of less than 1×10^{18} m^{-3}.

The third present invention provides a nitride based semiconductor photo-luminescent device having an active layer over a

mask-less epitaxial lateral overgrowth substrate having a stripe-shaped nitride based semiconductor pattern with a window region, the active layer having both at least a high dislocation density region positioned over the stripe-shaped nitride based semiconductor pattern and at least a low

5   dislocation density region positioned over the window region, and the low dislocation density region being lower in dislocation density than the high dislocation density region, wherein the low dislocation density region includes a current injection region into which a current is injected, and the active layer is less than 1×10^{18} m^{-3} in impurity concentration.

10   It is also preferable that a dislocation density of the low dislocation density region is not more than one tenth of a dislocation density of the high dislocation density region.

It is also preferable that a dislocation density of the current injection region is not more than one tenth of an averaged dislocation

15   density of the active layer.

It is also preferable that a dislocation density of at least a part of the high dislocation density region is not less than 1×10^{12} m^{-2}, and an average dislocation density of the current injection region in the low dislocation density region is less than 1×10^{11} m^{-2}.

20   It is also preferable that an average dislocation density of the active layer is not less than 1×10^{12} m^{-2}, and an average dislocation density of the current injection region in the low dislocation density region is less than 1×10^{11} m^{-2}.

It is also preferable that an average dislocation density of the

Page 28

current injection region is less than 1×10^{11} m^{-2}, and an average dislocation density of a peripheral region within a distance of 5 micrometers from the current injection region in the low dislocation density region is not less than 1×10^{12} m^{-2}.

5 It is also preferable that a current injection electrode is provided over an upper semiconductor layer overlying the active layer, and the active layer has an under-positioned region which is positioned under the current injection electrode, and an average dislocation density of the under-positioned region of the active layer is less than 1×10^{11} m^{-2}, and an

10 average dislocation density of a peripheral region within a distance of 5 micrometers from the under-positioned region is not less than 1×10^{12} m^{-2}.

It is also preferable that an average dislocation density of a peripheral region within a distance of 5 micrometers from the current injection region in the low dislocation density region is not more than one

15 tenth of an average dislocation density of the current injection region.

It is also preferable that a current injection electrode is provided over an upper semiconductor layer overlying the active layer, and the active layer has an under-positioned region which is positioned under the current injection electrode, and an average dislocation density of the under-

20 positioned region of the active layer is not more than one tenth of an average dislocation density of an average dislocation density of a peripheral region within a distance of 5 micrometers from the under-positioned region.

It is also preferable that a higher dislocation density region

having a dislocation density of not less than ten times of a dislocation density of the current injection region is present in a peripheral region within a distance of 5 micrometers from the current injection region.

It is also preferable that the window region has a width of not

5   less than 25 micrometers.

It is also preferable that the active layer is undoped.

It is also preferable that the active layer comprises a multiple quantum well structure comprising alternating laminations of undoped quantum well layers and undoped potential barrier layers.

10   It is also preferable that the active layer comprises a multiple quantum well structure comprising alternating laminations of undoped quantum well layers and Si-doped potential barrier layers having an impurity concentration of less than 1×10^{18} m^{-3}.

It is also preferable that the active layer comprises a multiple

15   quantum well structure comprising alternating laminations of Si-doped quantum well layers having an impurity concentration of less than 1×10^{18} m^{-3} and undoped potential barrier layers.

It is also preferable that the active layer comprises a multiple quantum well structure comprising alternating laminations of Si-doped

20   quantum well layers having an impurity concentration of less than 1×10^{18} m^{-3} and Si-doped potential barrier layers having an impurity concentration of less than 1×10^{18} m^{-3}.

PREFERRED EMBODIMENT

Page 30

FIRST EMBODIMENT :

A first embodiment according to the present invention will be described in detail with reference to the drawings. FIG. 2 is a fragmentary

5   cross sectional elevation view illustrative of a first novel nitride based semiconductor laser diode in a first embodiment according to the present invention. The first novel nitride based semiconductor laser diode has the following structure. A stripe-shaped silicon dioxide mask 103 having window regions is selectively formed over a gallium nitride layer 102 over

10   a top surface of a sapphire substrate 101, so that a gallium nitride layer is grown over the stripe-shaped silicon dioxide mask 103 and over the gallium nitride layer 102, wherein the gallium nitride layer has low dislocation density regions 104 which are positioned over the stripe-shaped silicon dioxide mask 103. Both a first type substrate having a silicon

15   dioxide mask width of 10 micrometers and a second type substrate having a silicon dioxide mask width of 25 micrometers are prepared.

A gallium nitride layer 102 is grown on the sapphire substrate 101 by a metal organic chemical vapor deposition method. The sapphire substrate 101 has a high surface dislocation density. The gallium nitride

20   layer 102 has a high dislocation density. A stripe-shaped silicon dioxide mask 103 having window regions is formed over the gallium nitride layer 102 in a [1,-1,0,0]-direction. A gallium nitride layer 106 is grown by a metal organic chemical vapor deposition method using the stripe-shaped silicon dioxide mask 103 with the window regions. The gallium nitride

layer 106 has a high dislocation density region 116 and a low dislocation density region 104. The high dislocation density region 116 is formed on the gallium nitride layer 102 having a high dislocation density. The high dislocation density region 116 is grown in a vertical direction from gallium

5 nitride layer 102 having a high dislocation density shown by the window regions of the stripe-shaped silicon dioxide mask 103, for which reason the dislocation is propagated from the gallium nitride layer 102 to the high dislocation density region 116, whereby the high dislocation density region 116 has a high dislocation density. The low dislocation density region 104

10 is formed over the stripe-shaped silicon dioxide mask 103. The low dislocation density region 104 is grown by the epitaxial lateral overgrowth from the window regions of the stripe-shaped silicon dioxide mask 103. The stripe-shaped silicon dioxide mask 103 cuts the further propagation of the dislocation from the sapphire substrate 101. The low dislocation density

15 region 104 has a low dislocation density. At the center of the low dislocation density region 104, epitaxial lateral overgrowths of gallium nitride in various lateral directions from the window regions of the stripe-shaped silicon dioxide mask 103 come together, whereby new dislocations are formed, for which reason the center region of the low dislocation

20 density region 104 has a high dislocation density. As a result, an Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100 is completed which has the high dislocation density region 116 and the low dislocation density region 104.

An Si-doped n-type $In_{0.1}Ga_{0.9}N$ layer 107 is formed over the Si-

doped n-type gallium nitride epitaxial lateral overgrowth substrate 100. An n-type cladding layer 108 is formed over the Si-doped n-type $In_{0.1}Ga_{0.9}N$ layer 107, wherein the n-type cladding layer 108 comprises 120 periods of alternating laminations of an Si-doped n-type GaN layer having a thickness

5   of 2.5 nanometers and an undoped $Al_{0.14}Ga_{0.86}N$ layer having a thickness of 2.5 nanometers. An Si-doped n-type GaN optical confinement layer 109 having a thickness of 0.1 micrometers is formed over the n-type cladding layer 108. A multiple quantum well active layer 110 is formed over the Si-doped n-type GaN optical confinement layer 109, wherein the multiple

10   quantum well active layer 110 comprises alternating laminations of undoped n-type $In_{0.15}Ga_{0.85}N$ quantum well layer having a thickness of 3.5 nanometers and an undoped n-type $In_{0.02}Ga_{0.98}N$ potential barrier layer having a thickness of 10.5 nanometers. An Mg-doped p-type $Al_{0.2}Ga_{0.8}N$ cap layer 111 having a thickness of 20 nanometers is formed

15   over the multiple quantum well active layer 110. An Mg-doped p-type GaN optical confinement layer 112 having a thickness of 0.1 micrometer is formed over the Mg-doped p-type $Al_{0.2}Ga_{0.8}N$ cap layer 111. A p-type cladding layer 113 is formed over the Mg-doped p-type GaN optical confinement layer 112, wherein the p-type cladding layer 113 comprises

20   120 periods of alternating laminations of an Mg-doped p-type GaN layer having a thickness of 2.5 nanometers and an undoped $Al_{0.14}Ga_{0.86}N$ layer having a thickness of 2.5 nanometers. An Mg-doped p-type GaN contact layer 114 having a thickness of 0.05 micrometers is formed over the p-type cladding layer 113. The lamination structure over the Si-doped n-type

Page 33

gallium nitride epitaxial lateral overgrowth substrate 100 is selectively removed by a dry etching process to form a ridge structure over a predetermined region of the top surface of the Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100, wherein the ridge structure comprises laminations of the Si-doped n-type $In_{0.1}Ga_{0.9}N$ layer 107, the n-type cladding layer 108, the Si-doped n-type GaN optical confinement layer 109, the undoped multiple quantum well active layer 110, the Mg-doped p-type $Al_{0.2}Ga_{0.8}N$ cap layer 111, the Mg-doped p-type GaN optical confinement layer 112, the p-type cladding layer 113 and the Mg-doped p-type GaN contact layer 114. The Mg-doped p-type GaN contact layer 114 is positioned over the low dislocation density region 104 for current injection into the low dislocation density region 104. A p-electrode 105 is formed on the Mg-doped p-type GaN contact layer 114, wherein the p-electrode 105 comprises an Ni layer and an Au layer. An n-electrode 115 is also selectively formed over the top surface of the Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100, wherein the n-electrode 115 comprises an Ni layer and an Au layer. The n-electrode 115 is also positioned over the low dislocation density region 104 for current injection into the low dislocation density region 104.

As compared to the above first and second types novel devices, third to sixth types devices were also prepared. The above first type device has the undoped active region and has the silicon dioxide mask pattern width of 10 micrometers, wherein the quantum well layers and the potential barrier layers are undoped. The above second type device has the undoped

Page 34

active region and has the silicon dioxide mask pattern width of 25 micrometers. The third to sixth types devices have the Si-doped active layers. The third type device has the silicon dioxide mask pattern width of 10 micrometers and the Si-impurity concentration of 1×10^{18} m^{-3} for each

5   of the quantum well layers and the potential barrier layers in the active layer. The fourth type device has the silicon dioxide mask pattern width of 25 micrometers and the Si-impurity concentration of 1×10^{18} m^{-3} for each of the quantum well layers and the potential barrier layers in the active layer. The fifth type device has the silicon dioxide mask pattern width of 10

10   micrometers and the Si-impurity concentration of 5×10^{18} m^{-3} for each of the quantum well layers and the potential barrier layers in the active layer. The sixth type device has the silicon dioxide mask pattern width of 25 micrometers and the Si-impurity concentration of 5×10^{18} m^{-3} for each of the quantum well layers and the potential barrier layers in the active layer.

15   Observations to the dislocations for each of the first to sixth types devices have been carried out by use of a transmission electron microscope. The high density dislocation region 116 and the low density dislocation region 104 are observed for each of the first to sixth types devices, wherein the dislocation density of the high dislocation density region 116 is about 5

20    $\times 10^{12}$ m^{-2}, and the dislocation density of the low dislocation density region 104 is about 2×10^{10} m^{-2}. A large difference in dislocation density was observed between the high dislocation density region 116 and the low dislocation density region 104. The dislocation density is measurable by the transmission electron microscope. The dislocation density may also be

Page 35

measurable by he etch-pit density. A mixture liquid of phosphoric acid and sulfuric acid is heated at 200°C. Samples of the above six types are dipped into the solution for about 1 hour to form etch-pits at the positions of the dislocations, wherein the etch-pit density almost corresponds to the

5   dislocation density.

If the dislocation density or the etch-pit density is low, then it is necessary for realizing a highly accurate measurement that the number of dislocations or etch-pits distributed in a large area is counted. For example, the dislocation density is about 1×10^{11} m^{-2}, then the area of at least $1 \times$

10   10^{-10} m^2 is necessary for the highly accurate measurement to the dislocation density or the etch-pit density. The area of at least 1×10^{-10} m^2 corresponds to a 10 micrometers squares. If the gallium nitride layer is grown over the epitaxial lateral overgrowth substrate, then the dislocation density has a large special variation in a direction perpendicular to the

15   longitudinal direction of the striped-shape silicon dioxide masks. It is preferable that the measurement is made in a rectangle-shaped area of 100 micrometers in a first direction and 1 micrometer in a second direction, wherein the first direction is parallel to the longitudinal direction of the striped-shape silicon dioxide masks, whilst the second direction is

20   perpendicular to the longitudinal direction of the striped-shape silicon dioxide masks.

Table 2 shows averaged values of individual initial threshold current densities of the first to sixth samples and the degrees of individual deteriorations thereof after APC examination for 100 hours under high

temperature and high output conditions of 70°C and 30 mW.

<div align="center">Table 2</div>

	Threshold current density	deterioration
First sample	22 (mA/m^2)	no deterioration
Second sample	24 (mA/m^2)	no deterioration
Third sample	24 (mA/m^2)	no deterioration
Fourth sample	23 (mA/m^2)	no deterioration
Fifth sample	23 (mA/m^2)	emission discontinuation
Sixth sample	23 (mA/m^2)	no deterioration

Threshold current density : initial threshold current density.

First sample :   epitaxial lateral overgrowth ;

silicon dioxide mask width of 25 micrometers ; and

Si-undoped active layer.

Second sample :   epitaxial lateral overgrowth ;

silicon dioxide mask width of 10 micrometers ; and

Si-undoped active layer.

Third sample :   epitaxial lateral overgrowth ;

silicon dioxide mask width of 25 micrometers ; and

Si-doped active layer of 1×10^{18} m^{-3}.

Fourth sample :   epitaxial lateral overgrowth ;

silicon dioxide mask width of 10 micrometers ; and

Si-doped active layer of 1×10^{18} m^{-3}.

Fifth sample :   epitaxial lateral overgrowth ;

silicon dioxide mask width of 25 micrometers ; and

Si-doped active layer of 5×10^{18} m-3.

Sixth sample : epitaxial lateral overgrowth ;

silicon dioxide mask width of 10 micrometers ; and

5 Si-doped active layer of 5×10^{18} m-3.

There was no large difference in the initial threshold current density in the above first to sixth samples. The fifth sample having the mask width of 10 micrometers and the Si-impurity concentration of $5 \times$

10 10^{18} m-3 for the active layer showed a remarkable deterioration, wherein the laser emission is discontinued before 100 hours operation, whilst the remaining first to fourth and sixth samples showed almost no deteriorations. The fifth sample was observed in dislocation by the transmission electron microscope. It was confirmed that the dislocations in the high dislocation

15 density region extend to the low dislocation density region.

Before this examination, the high dislocation density region of each of the above first to sixth samples was distanced by about 3 micrometers from the current injection region of the active layer. After the examination, the high dislocation density region of the fifth sample only

20 extends to the current injection region of the active layer. After the examination, the high dislocation density region of each of the above first and second samples remained distanced by about 3 micrometers from the current injection region of the active layer. Namely, the distribution of the dislocation density remained unchanged for the first and second samples

having the undoped active layers. For the sixth sample, it was observed that the dislocations extend from the high dislocation density region 116 by about 5 micrometers toward the low dislocation density region 104 but did not reach the current injection region of the active layer.

5   In accordance with this embodiment, if the high dislocation density region 116 is present within 5 micrometers from the current injection region of the active layer, the low impurity concentration of not more than 1×10^{18} m^{-3} of the active layer provides a remarkable effect of suppressing the dislocation motion and extension. If the active layer is

10   undoped or the silicon dioxide mask width is not less than 25 micrometers, then the movement or extension of the dislocation from the high dislocation density region to the low dislocation density region is suppressed, the life-time of the laser device under the high temperature and high output conditions is remarkably and greatly improved.

15   In order to show the effect of the improved life-time of the device in this embodiment, the comparative samples were prepared, which have various dislocation densities of the high dislocation density region and the low dislocation density regions. The APC examinations were made for each of the comparative samples under the high temperature and high

20   output conditions. The dislocation density is controllable by controlling the growth conditions for the selective growth process.

As a result, in accordance with the present embodiment, even if the dislocation density of the low dislocation density region is not more than one tenth of the dislocation density of the high dislocation density

Page 39

region, then the Si-undoped active layer results in no deterioration and provides the long life-time in consideration that the dislocation extends or moves from the high dislocation density region to deteriorate the device, if the spatial distribution of the dislocation density, for example, the in-plane

5   variation of the dislocation density is not so large, then the above effect is small and the above result is the natural result. If the dislocation density is uniform spatially, then no further effect of improving the life-time is obtained.

The impurity doping into the active layer means the impurity

10   doping into either any one or both of the quantum well layers and the potential barrier layers. Namely, all of the quantum well layers and the potential barrier layers in the active layer are undoped or Si-doped at an impurity concentration of less than 1×10^{18} m^{-3} in order to realize the long-life-time of the device.

15   In place of the multiple quantum well active layer, the single layered InGaN active layer is used for a further comparative examination. If the thickness of the single layered InGaN active layer is not less than 10 nanometers, then the low impurity concentration of less than 1×10^{18} m^{-3} provides no remarkable effect of improving the life-time as compared to

20   the multiple quantum well active layer. If the thickness of the single layered InGaN active layer is less than 10 nanometers to form a single quantum well layer for causing quantum effects, then the low impurity concentration of less than 1×10^{18} m^{-3} provides such the remarkable effect of improving the life-time as the multiple quantum well active layer.

Page 40

The following is one of the reasons why the effect of improving the life-time is less remarkable if the InGaN active layer comprises a thick single layered structure of the thickness of more than 10 nanometers in place of the quantum well structure and if the Si-impurity concentration is

5 less than 1×10^{18} m^{-3}. The reduction in the Si-impurity concentration of the thick single layered active layer increases the series resistance, whereby the heat generation is increased. The increase in the heat generation causes that even if the Si-impurity concentration is low, then the dislocations are likely to extend and move.

10 If the active layer comprises the quantum well structure, then the increase in the Si-impurity concentration shortens the life-time. As compared to the single layered active layer, a ratio in area of the interface to the volume of the active layer is remarkably increased. A segregation of the Si-impurity appears on the interface. Not only the interface

15 recombination speed is increased, but also the extension and move of the dislocations are enhanced.

As disclosed in Japanese laid-open patent publication No. 10-12969, other impurity such as Mg than Si is doped to reduce the threshold current density. If the other impurity is not doped into the active layer or

20 the active layer is Mg-undoped, the life-time is largely and greatly improved under the high temperature and high output conditions. The present inventors prepared the different devices having the undoped active layer and the Mg-doped active layer for carrying out the APC examination at 70°C and 30 mW. The deterioration of the device having the Mg-doped

Page 41

active layer is larger than the deterioration of the device having the undoped active layer.

In this embodiment, the novel nitride based semiconductor photo-luminescent device is applied to the semiconductor laser device. It is
5 of course possible to apply the novel nitride based semiconductor photo-luminescent device to other devices such as the light emission diode and the super luminescent diode.

In accordance with the novel nitride based semiconductor photo-luminescent device, the active layer has the high dislocation density region
10 and the low dislocation density region which has the current injection layer, and the active layer is less than 1×10^{18} m^{-3} in impurity concentration to suppress the Auger re-combination and also suppress the extension and movement of the dislocations from the high dislocation density region to the current injection region in the low dislocation density region, whereby
15 the life-time of the device under the high temperature and high output conditions is remarkably and greatly improved.

The nitride based semiconductor photo-luminescent device is formed over the mask patterns provided on the gallium nitride top surface of the epitaxial lateral overgrowth substrate, wherein said mask patterns
20 have a mask width of not less than 25 micrometers to increase the width of the low dislocation density region for suppressing the influence by the high dislocation density region and for obtaining the high reliability under the high temperature and high output conditions.

SECOND EMBODIMENT :

A second embodiment according to the present invention will be described in detail with reference to the drawings. FIG. 3 is a fragmentary cross sectional elevation view illustrative of a second novel nitride based

5   semiconductor laser diode in a second embodiment according to the present invention. The second novel nitride based semiconductor laser diode is formed over a mask-less epitaxial lateral overgrowth substrate. a gallium nitride layer 102 is grown over a top surface of a sapphire substrate 101 by a metal organic chemical vapor deposition. A stripe-shape silicon dioxide

10   mask 103 is formed over the gallium nitride layer 102, so that the gallium nitride layer 102 is then selectively etched by a dry etching process to form a stripe-shaped gallium nitride layer 301 with a window region. The stripe-shape silicon dioxide mask 103 is then removed from the stripe-shaped gallium nitride layer 301. An Si-doped n-type gallium nitride layer 302 is

15   grown by the metal organic chemical vapor deposition method over the stripe-shaped gallium nitride layer 301 with the window region, on which the top surface of the sapphire substrate 101 is shown, wherein the epitaxial lateral overgrowth appears over the top surface of the sapphire substrate 101 shown through the window region of the stripe-shaped gallium nitride

20   layer 301, whilst the normal epitaxial vertical growth appears over the stripe-shaped gallium nitride layer 301. The epitaxial lateral overgrowth forms the flat Si-doped n-type gallium nitride layer 302. The Si-doped n-type gallium nitride layer 302 has a low dislocation density region 104 which is positioned over the window region of the stripe-shaped gallium

nitride layer 301. The Si-doped n-type gallium nitride layer 302 has a high dislocation density region 116 which is positioned over the stripe-shaped gallium nitride layer 301.

A gallium nitride layer 102 is grown on the sapphire substrate

5   101 by a metal organic chemical vapor deposition method. The sapphire substrate 101 has a high surface dislocation density. The gallium nitride layer 102 has a high dislocation density. A stripe-shaped silicon dioxide mask 103 having window regions is formed over the gallium nitride layer 102 in a [1,-1,0,0]-direction for subsequent dry etching to the gallium

10   nitride layer 102 to form a stripe-shaped gallium nitride layer 301 with a window region. The stripe-shape silicon dioxide mask 103 is then removed from the stripe-shaped gallium nitride layer 301. An Si-doped n-type gallium nitride layer 302 is grown by the metal organic chemical vapor deposition method over the stripe-shaped gallium nitride layer 301 with the

15   window region, on which the top surface of the sapphire substrate 101 is shown, wherein the epitaxial lateral overgrowth appears over the top surface of the sapphire substrate 101 shown through the window region of the stripe-shaped gallium nitride layer 301, whilst the normal epitaxial vertical growth appears over the stripe-shaped gallium nitride layer 301.

20   The epitaxial lateral overgrowth forms the flat Si-doped n-type gallium nitride layer 302. The Si-doped n-type gallium nitride layer 302 has a high dislocation density region 116 and a low dislocation density region 104. The high dislocation density region 116 is formed on the stripe-shaped gallium nitride layer 301 having a high dislocation density. The high

Page 44

dislocation density region 116 is grown in a vertical direction from the stripe-shaped gallium nitride layer 301 having a high dislocation density, for which reason the dislocation is propagated from the stripe-shaped gallium nitride layer 301 to the Si-doped n-type gallium nitride layer 302,

5 whereby the high dislocation density region 116 has a high dislocation density. The low dislocation density region 104 is formed over the top surface of the sapphire substrate 101 shown through the window region of the Si-doped n-type gallium nitride layer 302. The low dislocation density region 104 is grown by the epitaxial lateral overgrowth from the Si-doped

10 n-type gallium nitride layer 302. The interface of the Si-doped n-type gallium nitride layer 302 to the sapphire substrate 101 cuts the further propagation of the dislocation from the sapphire substrate 101. The low dislocation density region 104 has a low dislocation density. At the center of the low dislocation density region 104, epitaxial lateral overgrowths of

15 gallium nitride in various lateral directions from the Si-doped n-type gallium nitride layer 302 come together, whereby new dislocations are formed, for which reason the center region of the low dislocation density region 104 has a high dislocation density. As a result, an Si-doped n-type gallium nitride mask-less epitaxial lateral overgrowth substrate 200 is

20 completed which has the high dislocation density region 116 and the low dislocation density region 104.

Both a first type substrate having a window region width of 10 micrometers and a second type substrate having a window region width of 25 micrometers are prepared.

Page 45

Further, an Si-doped n-type $In_{0.1}Ga_{0.9}N$ layer 107 is formed over the Si-doped n-type gallium nitride mask-less epitaxial lateral overgrowth substrate 200. An n-type cladding layer 108 is formed over the Si-doped n-type $In_{0.1}Ga_{0.9}N$ layer 107, wherein the n-type cladding layer 108

5   comprises 120 periods of alternating laminations of an Si-doped n-type GaN layer having a thickness of 2.5 nanometers and an undoped $Al_{0.14}Ga_{0.86}N$ layer having a thickness of 2.5 nanometers. An Si-doped n-type GaN optical confinement layer 109 having a thickness of 0.1 micrometers is formed over the n-type cladding layer 108. A multiple

10   quantum well active layer 110 is formed over the Si-doped n-type GaN optical confinement layer 109, wherein the multiple quantum well active layer 110 comprises alternating laminations of undoped n-type $In_{0.15}Ga_{0.85}N$ quantum well layer having a thickness of 3.5 nanometers and an undoped n-type $In_{0.02}Ga_{0.98}N$ potential barrier layer having a

15   thickness of 10.5 nanometers. An Mg-doped p-type $Al_{0.2}Ga_{0.8}N$ cap layer 111 having a thickness of 20 nanometers is formed over the multiple quantum well active layer 110. An Mg-doped p-type GaN optical confinement layer 112 having a thickness of 0.1 micrometer is formed over the Mg-doped p-type $Al_{0.2}Ga_{0.8}N$ cap layer 111. A p-type cladding layer

20   113 is formed over the Mg-doped p-type GaN optical confinement layer 112, wherein the p-type cladding layer 113 comprises 120 periods of alternating laminations of an Mg-doped p-type GaN layer having a thickness of 2.5 nanometers and an undoped $Al_{0.14}Ga_{0.86}N$ layer having a thickness of 2.5 nanometers. An Mg-doped p-type GaN contact layer 114

Page 46

having a thickness of 0.05 micrometers is formed over the p-type cladding layer 113. The lamination structure over the Si-doped n-type gallium nitride mask-less epitaxial lateral overgrowth substrate 200 is selectively removed by a dry etching process to form a ridge structure over a

5 predetermined region of the top surface of the Si-doped n-type gallium nitride mask-less epitaxial lateral overgrowth substrate 200, wherein the ridge structure comprises laminations of the Si-doped n-type $In_{0.1}Ga_{0.9}N$ layer 107, the n-type cladding layer 108, the Si-doped n-type GaN optical confinement layer 109, the undoped multiple quantum well active layer 110,

10 the Mg-doped p-type $Al_{0.2}Ga_{0.8}N$ cap layer 111, the Mg-doped p-type GaN optical confinement layer 112, the p-type cladding layer 113 and the Mg-doped p-type GaN contact layer 114. The Mg-doped p-type GaN contact layer 114 is positioned over the low dislocation density region 104 for current injection into the low dislocation density region 104. A p-electrode

15 105 is formed on the Mg-doped p-type GaN contact layer 114, wherein the p-electrode 105 comprises an Ni layer and an Au layer. An n-electrode 115 is also selectively formed over the top surface of the Si-doped n-type gallium nitride mask-less epitaxial lateral overgrowth substrate 200, wherein the n-electrode 115 comprises an Ni layer and an Au layer. The n-

20 electrode 115 is also positioned over the low dislocation density region 104 for current injection into the low dislocation density region 104.

As compared to the above first and second types novel devices, third to sixth types devices were also prepared. The above first type device has the undoped active region and has the window region width of 10

micrometers, wherein the quantum well layers and the potential barrier layers are undoped. The above second type device has the undoped active region and has the window region width of 25 micrometers. The third to sixth types devices have the Si-doped active layers. The third type device

5 has the window region width of 10 micrometers and the Si-impurity concentration of 1×10^{18} m^{-3} for each of the quantum well layers and the potential barrier layers in the active layer. The fourth type device has the window region width of 25 micrometers and the Si-impurity concentration of 1×10^{18} m^{-3} for each of the quantum well layers and the potential

10 barrier layers in the active layer. The fifth type device has the window region width of 10 micrometers and the Si-impurity concentration of 5×10^{18} m^{-3} for each of the quantum well layers and the potential barrier layers in the active layer. The sixth type device has the window region width of 25 micrometers and the Si-impurity concentration of 5×10^{18} m^{-3}

15 for each of the quantum well layers and the potential barrier layers in the active layer.

Observations to the dislocations for each of the first to sixth types devices have been carried out by use of a transmission electron microscope. The high density dislocation region 116 and the low density dislocation

20 region 104 are observed for each of the first to sixth types devices, wherein the dislocation density of the high dislocation density region 116 is about 5×10^{12} m^{-2}, and the dislocation density of the low dislocation density region 104 is about 2×10^{10} m^{-2}. A large difference in dislocation density was observed between the high dislocation density region 116 and the low

dislocation density region 104. The dislocation density is measurable by the transmission electron microscope. The dislocation density may also be measurable by he etch-pit density. A mixture liquid of phosphoric acid and sulfuric acid is heated at 200℃. Samples of the above six types are dipped

5   into the solution for about 1 hour to form etch-pits at the positions of the dislocations, wherein the etch-pit density almost corresponds to the dislocation density.

If the dislocation density or the etch-pit density is low, then it is necessary for realizing a highly accurate measurement that the number of

10   dislocations or etch-pits distributed in a large area is counted. For example, the dislocation density is about 1×10^{11} m^{-2}, then the area of at least 1×10^{-10} m^2 is necessary for the highly accurate measurement to the dislocation density or the etch-pit density. The area of at least 1×10^{-10} m^2 corresponds to a 10 micrometers squares. If the gallium nitride layer is

15   grown over the epitaxial lateral overgrowth substrate, then the dislocation density has a large special variation in a direction perpendicular to the longitudinal direction of the striped-shape silicon dioxide masks. It is preferable that the measurement is made in a rectangle-shaped area of 100 micrometers in a first direction and 1 micrometer in a second direction,

20   wherein the first direction is parallel to the longitudinal direction of the striped-shape silicon dioxide masks, whilst the second direction is perpendicular to the longitudinal direction of the striped-shape silicon dioxide masks.

Table 3 shows averaged values of individual initial threshold

Page 49

current densities of the first to sixth samples and the degrees of individual deteriorations thereof after APC examination for 100 hours under high temperature and high output conditions of 70℃ and 30 mW.

5

Table 3

	Threshold current density	deterioration
First sample	24 (mA/m^2)	no deterioration
Second sample	23 (mA/m^2)	no deterioration
Third sample	22 (mA/m^2)	no deterioration
Fourth sample	24 (mA/m^2)	no deterioration
Fifth sample	22 (mA/m^2)	emission discontinuation
Sixth sample	23 (mA/m^2)	no deterioration

Threshold current density : initial threshold current density.

First sample : mask-less epitaxial lateral overgrowth ;

15 silicon dioxide mask width of 25 micrometers ; and

Si-undoped active layer.

Second sample : mask-less epitaxial lateral overgrowth ;

silicon dioxide mask width of 10 micrometers ; and

Si-undoped active layer.

20 Third sample : mask-less epitaxial lateral overgrowth ;

silicon dioxide mask width of 25 micrometers ; and

Si-doped active layer of 1×10^{18} m^{-3}.

Fourth sample : mask-less epitaxial lateral overgrowth ;

silicon dioxide mask width of 10 micrometers ; and

Si-doped active layer of 1×10^{18} m^{-3}.

Fifth sample :   mask-less epitaxial lateral overgrowth ;

silicon dioxide mask width of 25 micrometers ; and

Si-doped active layer of 5×10^{18} m^{-3}.

5   Sixth sample :   mask-less epitaxial lateral overgrowth ;

silicon dioxide mask width of 10 micrometers ; and

Si-doped active layer of 5×10^{18} m^{-3}.

There was no large difference in the initial threshold current

10   density in the above first to sixth samples. The fifth sample having the

mask width of 10 micrometers and the Si-impurity concentration of $5 \times$

10^{18} m^{-3} for the active layer showed a remarkable deterioration, wherein

the laser emission is discontinued before 100 hours operation, whilst the

remaining first to fourth and sixth samples showed almost no deteriorations.

15   The fifth sample was observed in dislocation by the transmission electron

microscope. It was confirmed that the dislocations in the high dislocation

density region extend to the low dislocation density region.

Before this examination, the high dislocation density region of

each of the above first to sixth samples was distanced by about 3

20   micrometers from the current injection region of the active layer. After the

examination, the high dislocation density region of the fifth sample only

extends to the current injection region of the active layer. After the

examination, the high dislocation density region of each of the above first

and second samples remained distanced by about 3 micrometers from the

current injection region of the active layer. Namely, the distribution of the dislocation density remained unchanged for the first and second samples having the undoped active layers. For the sixth sample, it was observed that the dislocations extend from the high dislocation density region 116 by

5   about 5 micrometers toward the low dislocation density region 104 but did not reach the current injection region of the active layer.

In accordance with this embodiment, if the high dislocation density region 116 is present within 5 micrometers from the current injection region of the active layer, the low impurity concentration of not

10   more than 1×10^{18} m^{-3} of the active layer provides a remarkable effect of suppressing the dislocation motion and extension. If the active layer is undoped or the silicon dioxide mask width is not less than 25 micrometers, then the movement or extension of the dislocation from the high dislocation density region to the low dislocation density region is suppressed, the life-

15   time of the laser device under the high temperature and high output conditions is remarkably and greatly improved.

In order to show the effect of the improved life-time of the device in this embodiment, the comparative samples were prepared, which have various dislocation densities of the high dislocation density region and the

20   low dislocation density regions. The APC examinations were made for each of the comparative samples under the high temperature and high output conditions. The dislocation density is controllable by controlling the growth conditions for the selective growth process.

As a result, in accordance with the present embodiment, even if

the dislocation density of the low dislocation density region is not more than one tenth of the dislocation density of the high dislocation density region, then the Si-undoped active layer results in no deterioration and provides the long life-time in consideration that the dislocation extends or

5   moves from the high dislocation density region to deteriorate the device, if the spatial distribution of the dislocation density, for example, the in-plane variation of the dislocation density is not so large, then the above effect is small and the above result is the natural result. If the dislocation density is uniform spatially, then no further effect of improving the life-time is

10   obtained.

The impurity doping into the active layer means the impurity doping into either any one or both of the quantum well layers and the potential barrier layers. Namely, all of the quantum well layers and the potential barrier layers in the active layer are undoped or Si-doped at an

15   impurity concentration of less than 1×10^{18} m^{-3} in order to realize the long-life-time of the device.

In place of the multiple quantum well active layer, the single layered InGaN active layer is used for a further comparative examination. If the thickness of the single layered InGaN active layer is not less than 10

20   nanometers, then the low impurity concentration of less than 1×10^{18} m^{-3} provides no remarkable effect of improving the life-time as compared to the multiple quantum well active layer. If the thickness of the single layered InGaN active layer is less than 10 nanometers to form a single quantum well layer for causing quantum effects, then the low impurity concentration

of less than 1×10^{18} m^{-3} provides such the remarkable effect of improving the life-time as the multiple quantum well active layer.

The following is one of the reasons why the effect of improving the life-time is less remarkable if the InGaN active layer comprises a thick single layered structure of the thickness of more than 10 nanometers in place of the quantum well structure and if the Si-impurity concentration is less than 1×10^{18} m^{-3}. The reduction in the Si-impurity concentration of the thick single layered active layer increases the series resistance, whereby the heat generation is increased. The increase in the heat generation causes that even if the Si-impurity concentration is low, then the dislocations are likely to extend and move.

If the active layer comprises the quantum well structure, then the increase in the Si-impurity concentration shortens the life-time. As compared to the single layered active layer, a ratio in area of the interface to the volume of the active layer is remarkably increased. A segregation of the Si-impurity appears on the interface. Not only the interface recombination speed is increased, but also the extension and move of the dislocations are enhanced.

If the other impurity is not doped into the active layer or the active layer is Mg-undoped, the life-time is largely and greatly improved under the high temperature and high output conditions. The present inventors prepared the different devices having the undoped active layer and the Mg-doped active layer for carrying out the APC examination at 70°C and 30 mW. The deterioration of the device having the Mg-doped

active layer is larger than the deterioration of the device having the undoped active layer.

In this embodiment, the novel nitride based semiconductor photo-luminescent device is applied to the semiconductor laser device. It is

5   of course possible to apply the novel nitride based semiconductor photo-luminescent device to other devices such as the light emission diode and the super luminescent diode.

In accordance with the novel nitride based semiconductor photo-luminescent device, the active layer has the high dislocation density region

10   and the low dislocation density region which has the current injection layer, and the active layer is less than 1×10^{18} m^{-3} in impurity concentration to suppress the Auger re-combination and also suppress the extension and movement of the dislocations from the high dislocation density region to the current injection region in the low dislocation density region, whereby

15   the life-time of the device under the high temperature and high output conditions is remarkably and greatly improved.

The nitride based semiconductor photo-luminescent device is formed over the mask patterns provided on the gallium nitride top surface of the epitaxial lateral overgrowth substrate, wherein said mask patterns

20   have a mask width of not less than 25 micrometers to increase the width of the low dislocation density region for suppressing the influence by the high dislocation density region and for obtaining the high reliability under the high temperature and high output conditions.

The nitride based semiconductor photo-luminescent device is

formed over selectively provided gallium nitride layers over the semi-insulating substrate of the mask-less epitaxial lateral overgrowth substrate, wherein said selectively provided gallium nitride layers have at least a window region having a window width of not less than 25 micrometers to

5 increase the width of the low dislocation density region for suppressing the influence by the high dislocation density region and for obtaining the high reliability under the high temperature and high output conditions.

THIRD EMBODIMENT :

10 A third embodiment according to the present invention will be described in detail with reference to the drawings. FIG. 4 is a fragmentary cross sectional elevation view illustrative of a third novel nitride based semiconductor laser diode in a third embodiment according to the present invention. The third novel nitride based semiconductor laser diode

15 comprises a surface emitting laser diode with the following structure. A stripe-shaped multilayer mask 403 having window regions is selectively formed over a gallium nitride layer 102 over a top surface of a sapphire substrate 101, wherein the stripe-shaped multilayer mask 403 comprises 20 periods of alternating laminations of zirconium dioxide film and silicon

20 dioxide film. The stripe-shaped multilayer mask 403 serves as a bottom dielectric multilayer reflective mirror. A gallium nitride layer 106 is grown over the stripe-shaped multilayer mask 403 and over the gallium nitride layer 102, wherein the gallium nitride layer has low dislocation density regions 104 which are positioned over the stripe-shaped multilayer mask

403.

A gallium nitride layer 102 is grown on the sapphire substrate 101 by a metal organic chemical vapor deposition method. The sapphire substrate 101 has a high surface dislocation density. The gallium nitride

5   layer 102 has a high dislocation density. A stripe-shaped multilayer mask 403 having window regions is formed over the gallium nitride layer 102 in a [1,-1,0,0]-direction over a top surface of a sapphire substrate 101. A gallium nitride layer 106 is grown by a metal organic chemical vapor deposition method using the stripe-shaped multilayer mask 403 with the

10   window regions. The gallium nitride layer 106 has a high dislocation density region 116 and a low dislocation density region 104. The high dislocation density region 116 is formed on the gallium nitride layer 102 having a high dislocation density. The high dislocation density region 116 is grown in a vertical direction from gallium nitride layer 102 having a high

15   dislocation density shown by the window regions of the stripe-shaped multilayer mask 403, for which reason the dislocation is propagated from the gallium nitride layer 102 to the high dislocation density region 116, whereby the high dislocation density region 116 has a high dislocation density. The low dislocation density region 104 is formed over the stripe-

20   shaped multilayer mask 403. The low dislocation density region 104 is grown by the epitaxial lateral overgrowth from the window regions of the stripe-shaped multilayer mask 403. The stripe-shaped multilayer mask 403 cuts the further propagation of the dislocation from the sapphire substrate 101. The low dislocation density region 104 has a low dislocation density.

At the center of the low dislocation density region 104, epitaxial lateral overgrowths of gallium nitride in various lateral directions from the window regions of the stripe-shaped multilayer mask 403 come together, whereby new dislocations are formed, for which reason the center region of

5 the low dislocation density region 104 has a high dislocation density. As a result, an Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100 is completed which has the high dislocation density region 116 and the low dislocation density region 104.

A multiple quantum well active layer 110 is formed over the Si-

10 doped n-type gallium nitride epitaxial lateral overgrowth substrate 100, wherein the multiple quantum well active layer 110 comprises alternating laminations of undoped n-type $In_{0.15}Ga_{0.85}N$ quantum well layer having a thickness of 3.5 nanometers and an undoped n-type $In_{0.02}Ga_{0.98}N$ potential barrier layer having a thickness of 10.5 nanometers. An Mg-doped p-type

15 multilayer reflective mirror 413 is formed over the multiple quantum well active layer 110, wherein the Mg-doped p-type multilayer reflective mirror 413 comprises 40 periods of alternating laminations of an Mg-doped p-type $Al_{0.4}Ga_{0.6}N$ layer and an Mg-doped p-type GaN layer. An Mg-doped p-type GaN contact layer 114 having a thickness of 0.05 micrometers is

20 formed over the Mg-doped p-type multilayer reflective mirror 413. The lamination structure over the Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100 is selectively removed by a dry etching process to form a ridge structure over a predetermined region of the top surface of the Si-doped n-type gallium nitride epitaxial lateral overgrowth

substrate 100, wherein the ridge structure comprises laminations of the upper region of the gallium nitride layer 106, the undoped multiple quantum well active layer 110, the Mg-doped p-type multilayer reflective mirror 413, and the the Mg-doped p-type GaN contact layer 114. The Mg-

5   doped p-type GaN contact layer 114 is positioned over the low dislocation density region 104 for current injection into the low dislocation density region 104. A p-electrode 105 is formed on the Mg-doped p-type GaN contact layer 114, wherein the p-electrode 105 comprises an Ni layer and an Au layer. An n-electrode 115 is also selectively formed over the top

10   surface of the Si-doped n-type gallium nitride epitaxial lateral overgrowth substrate 100, wherein the n-electrode 115 comprises an Ni layer and an Au layer. The n-electrode 115 is also positioned over the low dislocation density region 104 for current injection into the low dislocation density region 104. A laser is emitted from a bottom surface of the sapphire

15   substrate 101 in a direction vertical to the bottom surface.

As compared to the above first type device, the second and third types devices were also prepared. The above first type device has the undoped active region, wherein the quantum well layers and the potential barrier layers are undoped. The second type device has the Si-doped active

20   region with the Si-impurity concentration of 1×10^{18} m^{-3} for each of the quantum well layers and the potential barrier layers. The second type device has the Si-doped active region with the Si-impurity concentration of 5×10^{18} m^{-3} for each of the quantum well layers and the potential barrier layers.

Observations to the dislocations for each of the first to third types devices have been carried out by use of a transmission electron microscope. The high density dislocation region 116 and the low density dislocation region 104 are observed for each of the first to third types devices, wherein

5   the dislocation density of the high dislocation density region 116 is about 5 $\times 10^{12}$ m^{-2}, and the dislocation density of the low dislocation density region 104 is about 2×10^{10} m^{-2}. A large difference in dislocation density was observed between the high dislocation density region 116 and the low dislocation density region 104. The dislocation density is measurable by the

10   transmission electron microscope. The dislocation density may also be measurable by he etch-pit density. A mixture liquid of phosphoric acid and sulfuric acid is heated at 200°C. Samples of the above six types are dipped into the solution for about 1 hour to form etch-pits at the positions of the dislocations, wherein the etch-pit density almost corresponds to the

15   dislocation density.

If the dislocation density or the etch-pit density is low, then it is necessary for realizing a highly accurate measurement that the number of dislocations or etch-pits distributed in a large area is counted. For example, the dislocation density is about 1×10^{11} m^{-2}, then the area of at least $1 \times$

20   10^{-10} m^2 is necessary for the highly accurate measurement to the dislocation density or the etch-pit density. The area of at least 1×10^{-10} m^2 corresponds to a 10 micrometers squares. If the gallium nitride layer is grown over the epitaxial lateral overgrowth substrate, then the dislocation density has a large special variation in a direction perpendicular to the

Page 60

longitudinal direction of the striped-shape silicon dioxide masks. It is preferable that the measurement is made in a rectangle-shaped area of 100 micrometers in a first direction and 1 micrometer in a second direction, wherein the first direction is parallel to the longitudinal direction of the

5   striped-shape silicon dioxide masks, whilst the second direction is perpendicular to the longitudinal direction of the striped-shape silicon dioxide masks.

The APC examination for 100 hours under high temperature and high output conditions of 70°C and 30 mW was carried out to the first to

10   third type devices.

There was no large difference in the initial threshold current density in the above first to third devices. The third type device having the Si-impurity concentration of 5×10^{18} m^{-3} for the active layer showed a remarkable deterioration, wherein the laser emission is discontinued before

15   100 hours operation, whilst the remaining first and second type devices showed almost no deteriorations. The third type device was observed in dislocation by the transmission electron microscope. It was confirmed that the dislocations in the high dislocation density region extend to the low dislocation density region.

20   Before this examination, the high dislocation density region of each of the above first to third type devices was distanced by about 3 micrometers from the current injection region of the active layer. After the examination, the high dislocation density region of the third type device only extends to the current injection region of the active layer. After the

examination, the high dislocation density region of each of the above first and second type devices remained distanced by about 3 micrometers from the current injection region of the active layer. Namely, the distribution of the dislocation density remained unchanged for the first and second type

5   devices having the undoped active layers and the Si-impurity concentration of 5×10^{18} m^{-3}.

In accordance with this embodiment, if the high dislocation density region 116 is present within 5 micrometers from the current injection region of the active layer, the low impurity concentration of not

10 more than 1×10^{18} m^{-3} of the active layer provides a remarkable effect of suppressing the dislocation motion and extension. If the active layer is undoped, then the movement or extension of the dislocation from the high dislocation density region to the low dislocation density region is suppressed, the life-time of the laser device under the high temperature and

15 high output conditions is remarkably and greatly improved.

If the other impurity is not doped into the active layer or the active layer is Mg-undoped, the life-time is largely and greatly improved under the high temperature and high output conditions. The present inventors prepared the different devices having the undoped active layer

20 and the Mg-doped active layer for carrying out the APC examination at 70°C and 30 mW. The deterioration of the device having the Mg-doped active layer is larger than the deterioration of the device having the undoped active layer.

In this embodiment, the novel nitride based semiconductor

photo-luminescent device is applied to the semiconductor laser device. It is of course possible to apply the novel nitride based semiconductor photo-luminescent device to other devices such as the light emission diode and the super luminescent diode.

5   In accordance with the novel nitride based semiconductor photo-luminescent device, the active layer has the high dislocation density region and the low dislocation density region which has the current injection layer, and the active layer is less than 1×10^{18} m^{-3} in impurity concentration to suppress the Auger re-combination and also suppress the extension and

10   movement of the dislocations from the high dislocation density region to the current injection region in the low dislocation density region, whereby the life-time of the device under the high temperature and high output conditions is remarkably and greatly improved.

The nitride based semiconductor photo-luminescent device is

15   formed over the mask patterns provided on the gallium nitride top surface of the epitaxial lateral overgrowth substrate, wherein said mask patterns have a mask width of not less than 25 micrometers to increase the width of the low dislocation density region for suppressing the influence by the high dislocation density region and for obtaining the high reliability under the

20   high temperature and high output conditions.

Whereas modifications of the present invention will be apparent to a person having ordinary skill in the art, to which the invention pertains, it is to be understood that embodiments as shown and described by way of illustrations are by no means intended to be considered in a limiting sense.

Accordingly, it is to be intended to cover by claims all modifications which fall within the spirit and scope of the present invention.